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# APPLICATION FOR LETTERS PATENT

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## Plasma Etching Methods

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## INVENTORS

**Guy T. Blalock**  
**David S. Becker**  
**Kevin G. Donohoe**

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# PLASMA ETCHING METHODS

## TECHNICAL FIELD

This invention relates to plasma etching methods.

## BACKGROUND OF THE INVENTION

Plasma etchers are commonly used in semiconductor wafer processing for fabrication of contact openings through insulating layers. A photoresist layer having contact opening patterns formed therethrough is typically formed over an insulative oxide layer, such as  $\text{SiO}_2$  and doped  $\text{SiO}_2$ . An oxide etching gas, for example  $\text{CF}_4$  is provided within the etcher and a plasma generated therefrom over the wafer or wafers being processed. The etching gas chemistry in combination with the plasma is ideally chosen to be highly selective to etch the insulating material through the photoresist openings in a highly anisotropic manner without appreciably etching the photoresist itself. A greater degree of anisotropy is typically obtained with such dry plasma etchings of contact openings than would otherwise occur with wet etching techniques.

One type of plasma etcher includes inductively coupled etching reactors. Such typically include an inductive plasma generating source coiled about or at the top of the reactor chamber and an electrostatic chuck within the chamber atop which one or more wafers being processed lies. The electrostatic chuck can be selectively biased as determined by the operator. Unfortunately when utilizing etching components having both carbon and fluorine, particularly in inductively

1 coupled etching reactors, a halocarbon polymer develops over much of  
2 the internal reactor sidewall surfaces. This polymer continually grows  
3 in thickness with successive processing. Due to instabilities in the  
4 polymer film, the films are prone to flaking causing particulate  
5 contamination. In addition, the build-up of these films can produce  
6 process instabilities which are desirably avoided.

7 The typical prior art process for cleaning this polymer material  
8 from the reactor employs a plasma etch utilizing  $O_2$  as the etching gas.  
9 It is desirable that this clean occur at the conclusion of etching of the  
10 wafer while the wafer or wafers remain *in situ* within the reactor  
11 chamber. This both protects the electrostatic chuck (which is sensitive  
12 to particulate contamination) during the clean etch, and also maximizes  
13 throughput of the wafers being processed. An added benefit is obtained  
14 in that the oxygen plasma generated during the clean also has the  
15 effect of stripping the photoresist from the over the previously etched  
16 wafer.

17 However in the process of doing this reactor clean etch, there is  
18 an approximate 0.025 micron or greater loss in the lateral direction of  
19 the contact. In otherwords, the contact openings within the insulating  
20 layer are effectively widened from the opening dimensions as initially  
21 formed. This results in an inherent increase in the critical dimension  
22 of the circuitry design. As contact openings become smaller, it is not  
23 expected that the photolithography processing will be able to adjust in  
24 further increments of size to compensate for this critical dimension loss.

1 Accordingly, it would be desirable to develop plasma etching  
2 methods which can be used to minimize critical dimension loss of  
3 contact openings, and/or achieve suitable reactor cleaning to remove the  
4 polymer from the internal surfaces of the etching chamber. Although  
5 the invention was motivated from this perspective, the artisan will  
6 appreciate other possible uses with the invention only be limited by the  
7 accompanying claims appropriately interpreted in accordance with the  
8 Doctrine of Equivalents.

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11 **BRIEF DESCRIPTION OF THE DRAWINGS**

12 Preferred embodiments of the invention are described below with  
13 reference to the following accompanying drawings.

14 Fig. 1 is a diagrammatic view of a plasma etcher utilized at one  
15 processing step in accordance with the invention.

16 Fig. 2 is a view of the Fig. 1 apparatus and wafer at a  
17 processing step subsequent to that depicted by Fig. 1.  
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## SUMMARY OF THE INVENTION

In but one aspect of the invention, a plasma etching method includes forming a polymer comprising carbon and a halogen over at least some internal surfaces of a plasma etch chamber. After forming the polymer, plasma etching is conducted using a gas which is effective to etch polymer from chamber internal surfaces. In one implementation, the gas has a hydrogen component effective to form a gaseous hydrogen halide from halogen liberated from the polymer. The hydrogen component is preferably one or more of  $H_2$ ,  $NH_3$  and  $CH_4$ . The conversion of the halogen, released from the clean into a hydrogen halide, renders it substantially ineffective in etching the substrate and thus reduces the critical dimension loss. In one implementation, the gas comprises a carbon component effective to getter the halogen from the etched polymer.

In another implementation, a plasma etching method includes positioning a semiconductor wafer on a wafer receiver within a plasma etch chamber. First plasma etching of material on the semiconductor wafer occurs with a gas comprising carbon and a halogen. A polymer comprising carbon and the halogen forms over at least some internal surfaces of the plasma etch chamber during the first plasma etching. After the first plasma etching and with the wafer on the wafer receiver, second plasma etching is conducted using a gas effective to etch polymer from chamber internal surfaces and getter halogen liberated from the polymer to restrict further etching of the material on the

1 semiconductor wafer during the second plasma etching. The first and  
2 second plasma etchings are ideally conducted at subatmospheric pressure  
3 with the wafer remaining *in situ* on the receiver intermediate the first  
4 and second etchings, and with the chamber maintained at some  
5 subatmospheric pressure at all time intermediate the first and second  
6 plasma etchings.

7 The halogen preferably comprises fluorine, chlorine or mixtures  
8 thereof. The gas at least during the second etching preferably includes  
9 oxygen, such as O<sub>2</sub>.

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12 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

13 This disclosure of the invention is submitted in furtherance of the  
14 constitutional purposes of the U.S. Patent Laws "to promote the  
15 progress of science and useful arts" (Article 1, Section 8).

16 It has been discovered that the polymer deposited on the internal  
17 walls of the etching chamber includes a significant concentration of  
18 fluorine. It is believed that the oxygen during the clean etching under  
19 plasma condition combines with the carbon and fluorine of the polymer  
20 liberated from the internal walls and forms carbon monoxide and carbon  
21 dioxide plus an activated or reactive fluorine species. Unfortunately,  
22 this liberated fluorine species is also apparently reactive with the silicon  
23 dioxide material on the wafer, which results in more etching of such  
24 material and the widening of the contact openings.

Referring to Fig. 1, a plasma etching reactor is indicated generally with reference numeral 10. Such includes sidewalls 12 having internal surfaces 14. One or more gas inlets 16 and one or more gas outlets 18 are provided relative to etching chamber 12. A pump 20 is associated with outlet 18 for exhausting and establishing desired subatmospheric pressure conditions within chamber 12 during processing.

Plasma etching reactor 10 in the described embodiment is configured as an inductively coupled plasma etcher having a wafer receiver 22 within chamber 12 in the form of an electrostatic chuck. A biasing source 24 is electrically coupled with receiver 22. An inductive plasma inducing source 26 is diagrammatically shown externally at the top of chamber 10.

In accordance with the preferred embodiment, a semiconductor wafer 30 is positioned upon wafer receiver 22 within chamber 12. Wafer 30 has previously been processed to have a photoresist layer 32 formed on an insulative oxide layer (not specifically shown) formed on the outer surface of wafer 30. Photoresist layer 32 has contact opening patterns (not specifically shown) formed therethrough which ideally outwardly expose selected portions of the underlying insulative oxide layer.

A desired vacuum pressure is established and maintained within chamber 12 utilizing vacuum pump 20. An example chamber pressure is from about 30 mTorr to about 5 Torr. Inductively coupled source 26 and chuck 22 are appropriately biased to enable establishment

1 of a desired plasma within and immediately over wafer 30. An example  
2 power range for inductively coupled source 26 is from 100 watts to  
3 about 2,000 watts, with wafer receiver 22 being negatively biased to an  
4 example of 100 - 400 volts. Receiver 22 can have a temperature which  
5 is allowed to float, or otherwise be established and maintained at some  
6 range, for example from about -10°C to about 40°C.

7 Desired etching gases are injected to within chamber 12 through  
8 inlet 16, or other inlets, to provide a desired etching gas from which  
9 an etching plasma is formed immediately over wafer 30. Such gas can  
10 comprise, for example, carbon and a halogen. An exemplary gas would  
11 be CF<sub>4</sub>. Etching is conducted for a selected time to etch contact  
12 openings within the insulative oxide material on semiconductor wafer 30  
13 through the contact opening patterns formed within photoresist layer 32.  
14 Unfortunately, a polymer layer 40 comprising carbon and the halogen,  
15 in this example fluorine, forms over some of internal surfaces 14 of  
16 plasma etch chamber 12 during such etching. Such polymer can also  
17 form over photoresist layer 32 (not specifically shown). Such provides  
18 but one example of forming a polymer comprising carbon and a halogen  
19 over at least some internal surfaces of a plasma etch chamber.

20 Referring to Fig. 2, and at the conclusion of the first plasma  
21 etching and with wafer 30 on electrostatic chuck 22, chuck 22 is ideally  
22 provided at ground or floating potential and second plasma etching  
23 is conducted using a gas effective to etch polymer from chamber internal  
24 surfaces 14. The gas ideally has one or more components effective to



1 etch photoresist layer 32 from substrate 30 and polymer from chamber  
2 internal surfaces 14 (both being shown as removed in Fig. 2). Further,  
3 such one or more components of the gas are selected to be effective  
4 to getter halogen liberated from the polymer to restrict further etching  
5 of the insulative oxide or other previously etched material on the  
6 semiconductor wafer during the second plasma etching.

7 In one example, the gettering component comprises hydrogen which  
8 combines with the halogen during the second plasma etching to form  
9 a gaseous hydrogen halide which has a low reactivity with material of  
10 the semiconductor wafer, and accordingly is withdrawn from the reactor  
11 through outlet 18. Example hydrogen atom containing gases include  
12  $\text{NH}_3$ ,  $\text{H}_2$ , and  $\text{CH}_4$ . One example gas for providing the hydrogen  
13 component to the chamber is forming gas which consists essentially of  
14  $\text{N}_2$  at about 96% or greater and  $\text{H}_2$  at about 4% or less, by volume.

15 In another example, the gettering component comprises a carbon  
16 compound. Examples include hydrocarbons, aldehydes (i.e.,  
17 formaldehyde) and ketones (i.e., methyl ketone). Hydrocarbons will  
18 typically getter the halogen as a hydrogen halide. Where the carbon  
19 compound comprises a C-O bond which survives the processing, the  
20 halogen will typically be gettered as  $\text{COA}_x$ , where A is the etched  
21 halogen. One example carbon containing gettering compound having a  
22 C-O bond is CO, produced for example within the plasma from injecting  
23  $\text{CO}_2$  to within the reactor.  
24

1 The gas also ideally comprises an additional oxygen component,  
2 such as O<sub>2</sub> or other material. Such facilitates etching of both polymer  
3 and photoresist over the substrate. Where the gas components comprise  
4 O<sub>2</sub> and a hydrogen atom containing component, the O<sub>2</sub> component and  
5 hydrogen atom containing component are preferably provided in the  
6 chamber during the second plasma etching at a volumetric ratio of at  
7 least 0.1:1 of O<sub>2</sub> to the hydrogen atom containing component. One  
8 reduction to practice example in a thirty-five liter high density plasma  
9 etcher included a feed for the second plasma etching of 60 sccm NH<sub>3</sub>  
10 and 1,000 <sup>sccm DB. 8/24/98</sup> ~~liters~~ per minute of O<sub>2</sub>. For a carbon containing compound,  
11 such is preferably provided at from about 5% to about 80% by volume  
12 of the oxygen/carbon compound mixture.

13 Plasma conditions within the chamber with respect to pressure and  
14 temperature and biasing power on induction source 26 can be the same  
15 as in the first etching, or different. Regardless, such first and second  
16 plasma etchings are ideally conducted at subatmospheric pressure where  
17 the wafer remains *in situ* on the electrostatic chuck intermediate the  
18 first and second etchings with the chamber being maintained at some  
19 subatmospheric pressure at all time intermediate the first and second  
20 plasma etchings.

21 In compliance with the statute, the invention has been described  
22 in language more or less specific as to structural and methodical  
23 features. It is to be understood, however, that the invention is not  
24 limited to the specific features shown and described, since the means

[illegible]